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Transferring concepts for urban modelling : capture or exchange?

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The recent multiplication of initiatives for an academic institutionalisation of the sciences of complex systems (as for instance the creation in Europe of half a dozen of dedicated schools or networks that are more or less inspired from the Santa Fe Institute) is a good indicator of the large developments that have brought that research field on the front stage during the last fifty years. The announced emergence of a perhaps mythical "science of complexity" is now challenging all sciences. It is very often suggested that the dynamic processes that lead to the emergence of sometimes unexpected structures from individual interactions can be analysed by using a common variety of concepts and tools, as provided by self-organisation theories and non linear mathematics. According to the Springer Complexity publication program, "These deep structural similarities can be exploited to transfer analytical methods and understanding from one field to another". We would like to question that claimed cross-fertilisation between scientific disciplines by drawing attention towards a few difficulties that are in practice associated to such a trans-disciplinary approach, especially when trying to develop a theory of complex systems that would be transversal to sciences in natural and social world.

Our laboratory has experienced the use of different modelling frames aiming at formalising, simulating and predicting the development of urban and regional systems: models of non linear differential equations under the paradigm of self-organisation theories (dissipative structures and synergetics (Pumain, Sanders, Saint-Julien, 1989, Sanders, 1992), as well as multi-agents systems in the context of artificial intelligence and theories of complexity (Bura et al., 1996). Since more than thirty years, urban modelling has progressed mainly by conceptual or even paradigmatic borrows from physics, mathematics, information theory or computation theory (Allen, 1997, Batty and Longley, 1994, Portugali, 2000, Weidlich, 2000, Pumain, 1998). We want to explore to what extent such notional transfers have contributed to urban theory. After noticing a reversal in the scientific paradigm beneficial to the "historical sciences" within the contemporary building of a "theory of complex systems", we review a series of misunderstandings or hiatus in the experimentation of various concepts that were transferred and applied to urban systems dynamics. In some respect, the practice of transfer is very often perverted by the relative social and epistemological status of the disciplines. We emphasize the need for a broader circulation of concepts and a wider attention paid to meaning and signification in applications.

1 Complexity: a reversal in the dominant scientific paradigm ?

Research on complex systems has lead to a paradoxical situation. For a long time, classical physics and mathematics have dominated the criteria of scientific work, as exemplified in the Popper model. Trying to be "scientific", social scientists had to resist to the simplifying hypothesis of this reductionism and could not meet the requirements of repeatability of experience and universality of results. Some sociologists as J.C. Passeron (1991) even imagine a specific way of reasoning for social sciences ("le raisonnement naturel"), because, even when falsifiable hypothesis can be formulated, their results never can be exactly repeated and abstracted from the context (historical or local) where they were established (or, the relevant contextual variables cannot be enumerated in an exhaustive way). Such a position is perhaps tactical and probably overestimates the effectiveness and rigour of the "hard sciences". Moreover, it seems to miss an essential turn in the recent evolution of a larger part of them, towards what is called "complexity".

New ideas that emerged in physical sciences with the development of dissipative structures (Prigogine, 1973) or synergetics (Haken, 1977) under the general label of complex systems dynamics have prepared a perhaps more general change in our way of thinking about systems. While these ideas were more and more applied to living species in the framework of an evolutionary thinking (Lewontin, 2003), or to adaptive cognitive systems in economy or social networks (Anderson, Arrow and Pine, 1988, Arthur, 1994, Arthur, Durlauf and Lane, 1997), the focus shifted from "self-organisation" of spatio-temporal patterns, from interactions between very large numbers of elementary particles in open systems submitted to external energy flows, towards the "emergence" of new structures and new properties stemming from the internal and/or external interactions between a limited number of heterogeneous elements or individuals, that may have reactive, adaptive and even cognitive behaviour, with sometimes a capacity for changing their interaction rules. The criteria in use for the definition of complex systems progressively evolved, including more and more aspects that were not often mentioned before. The systems "far from equilibrium" that are now under study, even in physical sciences, are explicitly considered in distinct contextual conditions of space and time. They come to meet the specific properties of the social systems, that were until now considered as diriment obstacles to any scientific formalisation: the irreversibility of temporal processes, the uniqueness of a system's trajectory in phase space, the non predictability of its future (Prigogine, 2001). All these features are now part of the theory of complex systems. New models have been developed for exploring fuzzy elements, strange attractors and uncertain events that were not considered before, and even human brains and thoughts have received a due attention in the new framework of cognitive sciences (Bourgine, Nadal, 2004).

It could be argued, as I did some time ago (Pumain, 1997), that social sciences should more than ever borrow their models from the sciences that are more advanced in formalisation, since these are now offering tools and concepts that no longer hurt the basic principles of research and knowledge about social systems. By applying ideas and models that have been developed within physics or mathematics of complex systems, we could learn more about the universe of possible evolutions framing the observed urban dynamics, and perhaps discover some abstract hidden processes (or formal theories) that could better explain the observed similarities appearing in urban structures and evolution, despite the overwhelming diversity of physical, economic, political and cultural forms that urban systems are exemplifying all over the world. I want to develop here the complementary idea that while the so-called (self-called?) "sciences of complexity" are evolving towards an attempt at unifying the analysis and, even if possible, "the" *theory*, of complex systems, social scientists should be keen on maintaining their previous knowledge as a most valuable input in the models that are now developed. Actually, that knowledge about social systems, although less formalised and incompletely integrated, already incorporates the principles that are today the distinguishing mark of complexity theory, and then should be recognized and integrated as such: heterogeneity of elements and their properties, diversity of interactions that are not only non-linear but often multi-scalar, dependence towards initial conditions and contextual variables, path dependency of the evolution, unpredictability of the future, irreducible role of intentional behaviour, intervention of the point of view of the observer in constructing the situation... Too often though, that specific knowledge was ignored, for instance by the enthusiastic promoters of “econophysics” (see for instance Durlauf, 2003) or “sociophysics” (fortunately there is nothing yet such as an “urbanophysics” ?).

Of course we are interested in the highly formalised concepts and powerful tools of complex systems sciences. But while experimenting new concepts and new modelling methods, we should keep in mind the objective of developing a relevant and sensible urban theory, that provides a really new contribution to knowledge in that field.

2 Quality of ontology and measurement for social systems

A first difficulty in applying the complexity paradigm to urban systems stems from the meaning of the word “complexity” itself. As the theory of complex systems aims at exploring how new entities, structures or properties emerge at a one observation level from the interactions between objects and behaviour or practices that are occurring at a lower level, a significant theory can be developed only if the objects, their attributes and their interactions that are under study are correctly identified. In the case of cities, this identification is not an easy task, for conceptual and for practical reasons.

On the theoretical side, there is a higher degree of complexity in social systems because of a higher difficulty in separating entities that would have clear limits and definite attributes, and because of the plurality of theories that frame the possibly relevant representations of these systems. One could for instance imagine to develop and refine many specific ontologies of the city as a complex system, that would define it either after its morphological properties as a progressive composition of buildings, or as a demographic aggregate of resident population constrained by the various and competitive needs of different age groups and professions, or as a portfolio of economic activities linked by agglomeration economies, or as the expression of the political and cultural organisation of a society articulating co-operative and conflicting groups, or as a place where the accumulated knowledge gives rise to the emergence of innovations… Each discipline of the social sciences participating to urban research has developed its own dynamic models of the city as a complex system, including non linear feed-backs effects and using differential equations or agent based computational representations for their simulation. Though, when implemented in a model, any of these partial representations would require the consideration of some important features that were not included in the model, as soon as a confrontation with the real world is to be tempted: in most cases, the evolution of any observed city, even when restricted to a narrow disciplinary description, is controlled by more than one of the features mentioned above. For instance, the ecological resources are necessary to explain some industrial urban specialisation, even if they are not part of a “pure” economic theory of the city; land values and urban densities can be related in a single model but applications will require precisions about collective values and land regulation policies… Even if these models could be conceived as “purely” theoretical, there is little doubt that they would miss most of the specificity of urban dynamics, that is precisely made of permanent adjustments between many of the possible determinants of urban evolution (as morphology, demography, economy, policy or culture).

According to J. Casti (1994), complexity is not an intrinsic property of systems but a subjective view of an observer confronted to the “surprise” of emerging properties (see also Batty, Torrens, 2001), and the degree of complexity of a system is directly proportional to the number of equivalent ways (models) in which the system can be described for explaining them. Following that view, we could then argue that the complexity of urban systems could be measured by the diversity of the several distinct representations of what a city is and how it functions. However, what are the "equivalent models" in the field of social sciences? Can they be assimilated to different explanations that are considered as satisfying by one particular discipline in a given theory within the field of urban research? Actually, these explanations are not "equivalent", since they do not give an alternative interpretation for the same reality, but they build a coherent view of a particular aspect of that reality. The various disciplinary approaches have to be articulated to reconstruct a comprehensive description of the city as a complex system. We can then suggest that, besides the definitions that have been proposed for complex systems, either mathematical or computational, social scientists could have their own complementary interpretation of complexity. The level of complexity of any situation (or dynamics) could be evaluated by enumerating the number of disciplinary concepts or points of view that would be necessary to provide an explanation of that situation, that can be considered both consistent and sufficient, according to an operational purpose or to a degree of precision of the description that is thought of as acceptable. That view is possible since social sciences built themselves and differentiated from each other by deepening the knowledge in one specific aspect of society, but while getting more and more insights in one direction they discover very often that they have to include within the description of the context of their study many other aspects that are developed by other disciplines. This is especially the case when cities are considered in the complexity of their evolution. A consequence is the need for periodically building new interfaces between disciplines of the social sciences (see section 4 below).

In this respect, the specific contribution of geography to the theory of cities as complex systems could be, not only in the traditional consideration of the phenomenological diversity of cities according to regions of earth space and historical times of societies, but also in the recognition of the multi-scalar character of urban systems. The seminal expression by B. Berry of "cities as systems within systems of cities" coins the ontological definition of urban systems by geographers. Of course that expression, that refers to the nested hierarchy as typical of the "architecture of complexity" as conceived by H. Simon at the beginning of the sixties, has to be questioned and updated, for instance with regard to modern communication systems, leading perhaps to a reformulation that would make a larger place to long distance and non hierarchical interactions in the former quasi-nested representation of two levels in urban systems. But in the building of a trans-disciplinary approach, we shall meet another difficulty. According to the principle of decomposability that, together with predictability and linearity, makes the difference between simple and complex systems, if there is some relevance in the concept of a "system of cities", and if that system is complex, then the consideration of a single city as disconnected from the whole system would change its dynamics. That connection between one city and the system of cities is missing in the economic theory of "the" city and even in the "new economic geography" (Fujita, Krugman and Venables, 1999). The lack of recognition of the constraint exerted by the existence of other cities on urban dynamics is probably a major weakness of the new urban economics, despite the important advances that were made in that field of research during the last decades.

So the acceptance of a point of view about cities as complex systems would mean that social sciences do co-operate in the elaboration of the theory. Even when it is well defined for one level of analysis, the theoretical conceptualisation of cities should include aspects of the context that are relevant for the dynamics under study. How many analyses of urban sprawl take for granted a description of properties of a "centre" and a "periphery" that are inspired by a cultural representation of American cities and derive corresponding attributes, without considering the values that are attached to the locations (as expressed for instance by the spatial distribution of land values, or urbanism regulations) within the country where the model is applied? The same carefulness should be required when defining the individual interactions that shape a system's structure: even if Shelling's model of social segregation provides a beautiful case of a non desirable unintentional collective result of intentional individual behaviour, it probably overestimates the intensity of segregationist practices, for instance by not allowing the residents that are satisfied to move, as the non satisfied do. Once again, the benchmark of their possible application to a diversity of observed situations seems to remain a necessary part of the construction of models and theories.

The same definitional accuracy should be applied to the apparently more trivial question of data collection for empirical analysis or model testing. We shall give only one example that could become a source of problem with the growing craze for the question of scaling (Pumain, 2004). Scaling processes are essential in complex systems dynamics, because they are probably rooted in very general constraints on the organisation, through the circulation of energy or information (West,). Urban systems are very likely to arouse many attempts of conceptualisation through scaling laws, because many empirical regularities have already been observed and modelled by Pareto distributions or fractal geometry. The spatial distribution of residential population densities or land prices, as well as Zipf's rank size rule, or Christaller's central place theory, do suggest the relevance of scaling processes for explaining the urban density gradient or the persistent inequalities in city sizes and functions. However, discovering new expressions of scaling laws cannot merely result from adding a new experiment on any urban data. If scaling effects are suspected, the data in use must be relevant for the process under study and the quality of their measurement has to be very high. Of course, the question of the definition and delimitation of urban entities in space and during the course of time is very difficult and their comparison within and between countries remain a delicate exercise. But it is not sufficient to use existing definitions and data bases if they do not represent meaningful entities for the analysed process.

For instance, many authors use the urban data base that give the populations of the cities of United States as a benchmark for testing Zipf's of Gibrat's models. But the SMSAs that are included do not represent without bias an entire urban system: as an SMSA is defined around a centre (urbanised area or continuously built-up surface) that groups at least 50 000 jobs, a number of smaller urban centres, although still functioning as urban agglomerations, are neglected. This lack in information has been acknowledged recently (in 2000) by the Bureau of Census who decided to add "micropolitan" statistical areas (including centres with 10 000 jobs) to the set of SMSAs. Many tests of models that try to relate the distribution of city sizes and growth processes have nevertheless used that data base for model testing, as did for instance Gabaix and Ioannides (1999), and Spyros (2003). Although the models these authors develop are each very interesting, their conclusions cannot be totally reliable because of this bias in data. Moreover, it is well known that the United States are not a representative case for all systems of cities, because during the last two centuries of its development the US system mixes classical dynamic processes of distributed growth in a mature system of cities together with more specific processes of expansion through new frontier settlements. The results of such experiments cannot be generalised (for instance to Europe and Asia where urban systems have a pluri-secular and most of times more than millennial history) and cannot make definitive conclusions in terms of a model that would become a reference for every urban system.

Another example of the importance of a correct definition of geographical urban entities for measuring urban growth processes is given by comparing the studies of Batty (2003) on Britain and Bretagnolle et al. (2000 and 2002) for Europe and France. Both try to identify a trend in urban concentration or dispersion at the scale of a system of cities during a long time period, by adjusting a Pareto model to the distribution of city sizes at different dates. But while Bretagnolle et al. use the definition of urban agglomerations (that can expand in space over time), Batty refers to an exhaustive partition of Britain, measuring the evolution of population within the stable 459 municipalities of England, Scotland and Wales between 1901 and 1991. Of course there is in that last case a possible bias in measuring the variance in urban population size, since the largest urban agglomerations are not allowed to overcome the limits of their municipality, their growth may be underestimated, while at the other end of the distribution of town sizes, the urban agglomerations that became smaller than their municipality limits have their population overestimated. This difference in data is likely to explain, at least for a part, the differences in results showing, after the values of the slopes of the adjusted distribution, a trend towards deconcentration in Britain versus a reinforcement of the urban hierarchy in the European and French study. The problem of comparability of data in space and time has to be solved if one wants to rise correct conclusions about the observed evolutionary trend, in order to further elaborate about the theory of the dynamics of systems of cities (Pumain, 2000).

We should then make a plea for using and helping to develop more comparable urban data bases. We do regret that the most recent attempt by Eurostat (programme named Urban Audit II, 2003) that includes a very carefully designed survey (more than 300 variables) will provide urban data that are meritoriously comparable in their statistical definition but absolutely not in the spatial framework of the urban entities under consideration: the delimitation of the urban entities according to the different European states varies in this document from political agglomeration (France), to NUTS3 (Spain) or NUTS4 (UK) regions… There were however previous successful attempts for providing comparative information at the scale of all European urban agglomerations, for historical periods (Bairoch et al. 1988, de Vries, 1984). At the world scale, the very exhaustive Geopolis data base prepared by F. Moriconi-Ebrard (1994) has been too rarely used and quoted as a powerful instrument for international comparisons using the best comparable definition and reliable delimitation of urban entities (Pumain, Moriconi, 1997). Another example of a cautious comparative attempt in urban comparison for scaling has been recently made by M. Guérois who used remote sensing data for comparing the shape of the urban field in different European countries (Guérois, 2003, Guérois, Pumain, 2004). Using the CORINE Land Cover data set, she was able to demonstrate that the urbanised areas are distributed around the main historical urban centres according to a dual density gradient, one rather steep corresponding to the urban agglomeration (with a radial fractal dimension between 1.7 and 1.9) and the other with much less contrasts representing the rural part of the functional urban area (automobile commuting zone, with a fractal dimension less than 1). More careful measurements like this are needed for a better understanding and significant modelling of the spatial expression of urban morphology and dynamics.

3 Cumulativity of knowledge

Another difficulty in the development of applications of new ideas and tools for complex systems to cities is in establishing connections between the ancient and that new knowledge. Knowledge accumulation, after remaining for a long time an academic and educational problem (UNESCO, 2003) and a preoccupation for archivists and museums, has become during the last decades a major political and economic issue. Being now considered as an important input in production, besides labour and capital, the scientific and technological achievements lead to the development of a new discipline, the “economy of knowledge”. At the same time, the epistemological thinking tended to avoid the debate about what we call the “cumulativity of knowledge”: it relates to the scientific and sociologic conditions that permit knowledge accumulation. The post structuralist deconstructivism as well as the postmodernist theories insisted on the plurality of “systems of knowledge” and the parallelism of theories that were alternative explanations and could not be cumulated.

To a large extent, many explorations that were conducted in the field of urban research for the sake of using concepts and tools of complexity theories did not try so much to contribute to knowledge accumulation in that field. Their main objective was not so much to connect their results to the existing state of knowledge in the domain than to underline the originality and novelty of their approach. We review here in detail one example, not as a criticism of that particular work that provides in other respects an excellent contribution, but as an illustration of the too limited use of what could be one of the most interesting and promising approach of the dynamics of urban networks. We refer to a paper by Anderson et al. (2003). They use an algorithm building « scale-free » networks for describing the distribution of land prices in an urban system. A “scale-free network” corresponds to a class of growing networks whose node degrees are power law distributed. In their model, the nodes of the network represent pieces of land which become over time more and more connected by edges representing exchanges of goods and services (actually the result of this trade is simulated by a trade benefit or financial investment directed from one node to another). The model proceeds by adding new links between already developed nodes, with a probability that is proportional to the relative size of the node in the total of nodes, and by selecting new nodes. The mean probability of developing existing nodes is significantly higher than the one attached to the development of new nodes. Spatial rules are added for specifying this selection process, according to hypothesis about a distance-decay interaction model. The model is calibrated in order to fit an impressive empirical data set about land values in Sweden (almost 3 millions observations). The paper demonstrates the ability of the model to reproduce the global statistical distribution (frequency of land squares according to land price) and its main parameter (Pareto exponent of 2.1). The authors assume a linear relationship between the value per unit of urban land and the size of urban population, so their model could be used as a starting point for fitting population data as well.

But the paper is not clear about the scale of application of the model: whereas referring at first to Zipf’s law, which is a model of the interurban distribution of city sizes, it represents “systems of specialised trading activities” that “can be resolved to any resolution down to individual transactions”, whereas the explanation of the model in “an urban economy context” seems to refer mainly to intra-urban land values formation (for instance, looking at different processes at the perimeter of urban areas and predicting the emergence of urban sub-centres). In any case, the model predicts a single and unified statistical distribution of land values at a country scale, making no distinction between the intra-urban gradient of land prices and the interurban distribution of land values. The model produces only a sharp break between rural and urban land values. To be coherent with the existing state of knowledge, the authors should have tested the variations of land prices inside the nodes (between centres and peripheries) as well as between the aggregated nodes. It could happen that the rather high level of inequalities they find between land prices is more linked with intra-urban inequalities than to interurban. Actually, when looking at he average housing, offices and land prices per urban area in

Europe, one discovers that prices are surprisingly similar from one city to the next (low variance) and the correlation with city size (as measured by population figures) is rather low for the entire distribution (even if large cities as London or Paris have the highest prices). Meanwhile, the inequalities between the prices per hectare inside the same single city may reach a factor 10 and more, at the block level, and frequently 5 or 6 at the scale of neighbourhoods (Fen Chong, Pumain, forthcoming).

4 Conclusion: organising a more symmetrical trans-disciplinary communication

Within the framework of the developing theory of complex systems, urban research is more and more open to the use of the large variety of concepts and tools that are imported from the more formalised sciences. While welcoming the appeal towards a general use of these references for urban modelling and theoretical elaboration, we have claimed for more caution and perhaps a better reciprocity in this process of transferring notions between disciplines. The modern paradigm of complexity being more and more inspired by conceptions that are emanating from social sciences, the methods that are now in use for research should not forget about the specific procedures for identifying and selecting relevant entities and processes that were specifically elaborated for the complex systems they are studying. As social scientists, we should not loss our specific expertise, the knowledge that was accumulated from past experiences using other methods but still valid and reusable, even if, as always, revisable.

We have underlined the originality of the representation of multi-scale urban systems that is built by urban geographers, and its high compatibility with the paradigm of complexity. However, in order to be recognised as more than a descriptive discipline among social sciences, there is a need for geography to build and communicate better formalised representations of its specific knowledge, by the means of basic theories and models. This theoretical approach did perhaps not progress enough since the seminal attempts by W. Bunge or W. Tobler. Why do we hesitate to formulate normalised geographical views of the city, or of systems of cities? Do we have to define an “homo geographicus”? Or can we borrow individual attributes and behavioural rules to other disciplines? Because economics was the first discipline in social sciences that undertook its formal and mathematical formalisation, a specific attention should be devoted to its approaches of urban systems. It is likely for instance that the Dixit-Stiglitz model of centre-periphery will become a building block for many urban models, as suggested by Fujita, Krugman and Venables (1999). However, the inter-disciplinary circulation of concepts and models should be two-ways, if one wants to avoid strange false innovations! For instance, Fujita et al. recommend to adopt the distinction made by Cronon of “first nature” and “second nature” advantages in location. The first correspond to advantages stemming from pure natural resources whereas the latter would be linked to man-made investments on the spot. Is that distinction really theoretically useful and necessary? Geographers have demonstrated for long that practically in all places the distinction is no longer possible to be made (as human intervention in modifying the quality of the site have been ancient and numerous), but that a very fruitful distinction in location advantages could arise when scale effects are recorded as site and situation. Improving the dialogue about such a question could be profitable to the two disciplines.

There is to avoid the periodical reinvention of the wheel, the misuse or neglect of former discoveries, the dilapidation of our intellectual heritage and to organise its preservation for the future (“to the generation before us”, as said the dedication of the textbook by Abler, Adams and Gould). Something like sustainable development in science?

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